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Design and Performance Analysis of a Compact 2.45 GHz Monopole Antenna for High-Efficiency Bluetooth and WLAN Applications

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A B S T R A C T

In this paper, a design of monopole antenna is presented for Wi-Fi and Bluetooth applications. The antenna operate at a frequency of 2.45 GHz, making it suitable for Wireless Local Area Network (WLAN) and Bluetooth communication systems. This antenna addresses the requirement for low cost, small size, light weight, and ease of installation, which are critical for high-performance Bluetooth and Wi-Fi applications [1]. The monopole antenna incorporates a meandering technique for size reduction. The design is based on quarter-wave impedance matching and use a T-junction power divider. The antenna is simulated, fabricated, and tested using various tools such as Microwave Office, AutoCAD, and Marconi Scalar Analyzer 6204. The results show that the proposed antenna achieved good return loss performance with limited bandwidth, making it effective candidate for Bluetooth and Wi-Fi communication devices operating at 2.45 GHz.

Keywords: Bluetooth applications, WLAN, monopole antenna, 2.45 GHz, transmission line model, quarter-wave impedance matching, T-junction power divider, return loss, antenna design, wireless communication

1. Introduction

The rapid advancement in wireless communication technologies has fueled the demand for compact and efficient antennas, especially in miniature devices. As cellular and wireless services expand, the development of antennas that meet the requirements for multiple communication standards, such as GSM, WLAN, Bluetooth, and LTE, has become essential [1] . With devices becoming smaller and more powerful, the focus has shifted towards designing compact printed antennas, specifically monopole antennas, that offer high performance while maintaining a minimal form factor. Monopole antennas are widely used in mobile and wireless applications due to their simplicity, ease of fabrication, and suitability for integration into small devices [2] .

Different frequency bands are allocated by international regulatory bodies to prevent interference between communication standards . However, white spaces, which are unutilized portions of the radio spectrum, present new opportunities for wireless communication. Cognitive radio systems can dynamically access these white spaces to improve spectrum efficiency and avoid destructive interference [3] . By sensing their environment, these systems adapt to the available spectrum, making them highly suitable for modern wireless applications [4]. This paper focuses on the design of a compact printed monopole antenna, optimized for Bluetooth and WLAN applications at 2.45 GHz. The proposed antenna design meets performance requirements while maintaining a small size, making it ideal for integration into miniature portable devices.

Nomenclature

WLAN: Wireless Local Area Network

Bluetooth: Short-range wireless technology standard

GHz: Gigahertz, a unit of frequency equal to one billion hertz

Return Loss (S-Parameter): A measure of the power reflected from the antenna, often represented as the S11 parameter

VSWR: Voltage Standing Wave Ratio, an indicator of impedance matching

Gain: The measure of an antenna's ability to direct or concentrate radio frequency energy in a particular direction

Radiation Pattern: The directional distribution of radiated power from an antenna

T-junction Power Divider: A device used to split or combine power between two paths in an RF circuit

CST Design Environment: Simulation software for electromagnetic design

ISM Band: Industrial, Scientific, and Medical radio bands, a set of frequencies reserved internationally for non-commercial use

2. Structure of Proposed Antenna

Numerous techniques and antenna designs have been employed for Bluetooth and WLAN systems, ranging from microstrip patches to monopoles and PIFAs , with various shapes such as meander and folded structures. The most common types for these applications include microstrip patch and monopole antennas, which offer compact and cost-effective solutions.

The proposed antenna design features a shorted patch and a monopole configuration, as depicted in Figure 1. The antenna is fabricated using an FR4 substrate, chosen for its affordability and availability. The overall dimensions of the antenna are 32 mm × 16 mm × 1.6 mm, making it highly suitable for small device integration.

Key design parameters include the dielectric constant (εr = 4.4), operating frequency of 2.45 GHz, and a substrate thickness of 1.6 mm. Unlike traditional designs, the antenna's ground plane covers only a portion of the substrate, allowing for a more compact form factor while maintaining the desired performance characteristics. This design ensures that the antenna provides reliable performance for Bluetooth and WLAN applications.

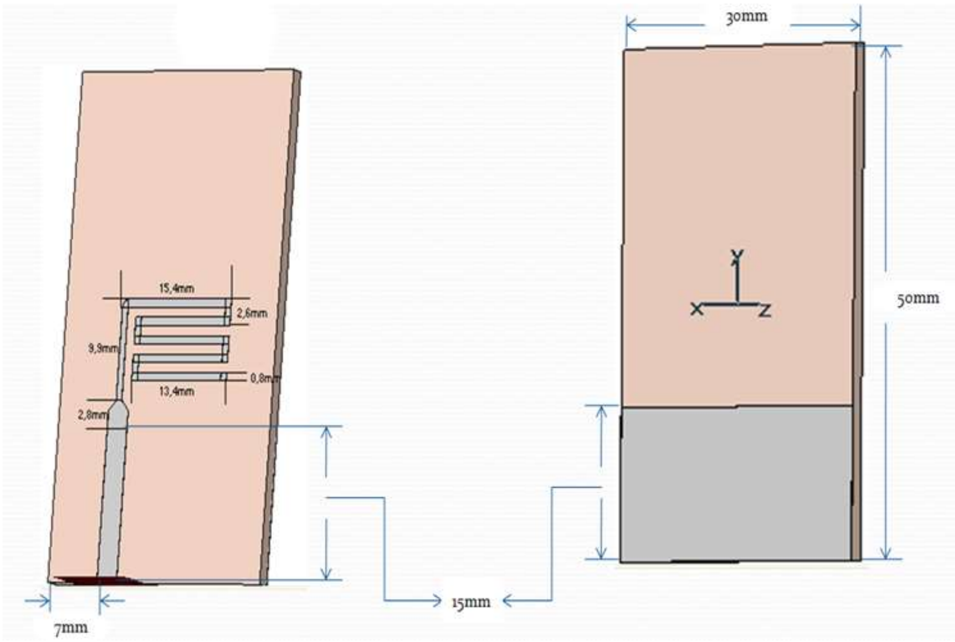

Fig 1- Geometry and dimensions of proposed antenna (in mm)

2.1 Simulation Results of Proposed Antenna

All table The proposed antenna was simulated and optimized using the Microwave Office software. Several design parameters were considered during the simulation, including return loss (S-parameter), Voltage Standing Wave Ratio (VSWR), gain, and radiation pattern. The return loss and VSWR were used to assess the bandwidth performance of the antenna [5] , while the gain and radiation pattern helped evaluate its radiation efficiency and directivity. These parameters provide insights into the antenna’s overall performance, ensuring that it meets the requirements for Bluetooth and WLAN applications at 2.45 GHz [6].

2.2 Return Loss Plot

The S11 parameter indicates the amount of power reflected from the antenna, often referred to as the reflection coefficient. Figure 2 illustrates the return loss plot for the proposed antenna, designed specifically for WLAN and Bluetooth applications in mobile systems. Utilizing a wave port configuration, the S11 plot is obtained with a threshold level of -10 dB, indicating that less than 10% of the total power is reflected.

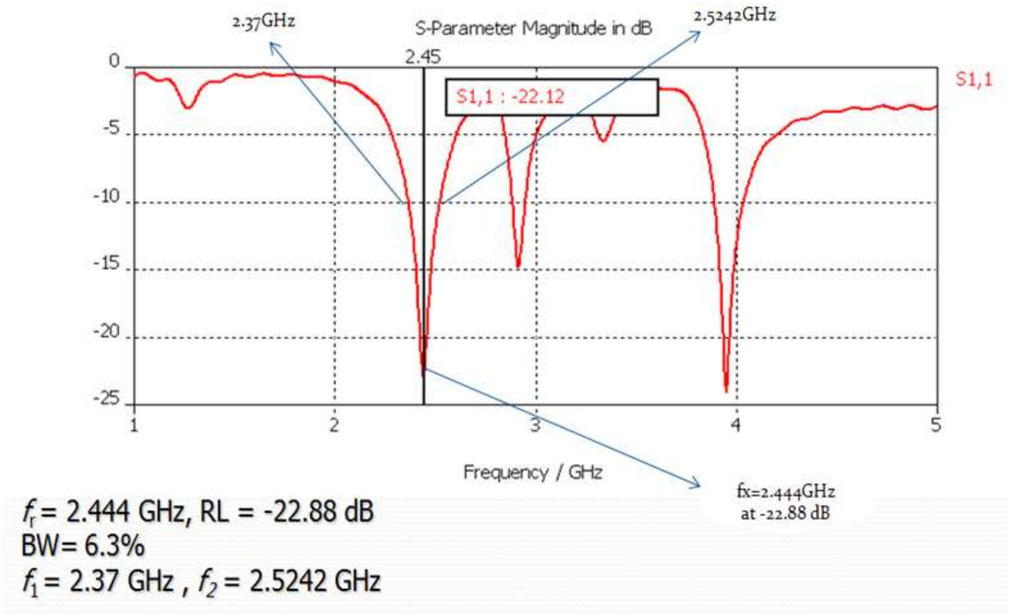

Fig 2 - Simulated Return Loss Plot of the Proposed Antenna

The proposed antenna is specifically designed for WLAN and Bluetooth applications in small devices, allowing it to operate effectively within the 2.45 GHz band. This model achieves a return loss of less than -10 dB, indicating efficient performance, and exhibits a radiation pattern that is well-suited for both WLAN and Bluetooth use cases. Figure 2 illustrates the simulation results for the monopole antenna design, generated using the CST Design Environment electromagnetic simulation software.

The analysis reveals that at the resonant frequency of 2.444 GHz, the return loss (RL) measures -22.88 dB. The operational bandwidth ranges from 2.37 GHz to 2.5242 GHz, yielding a bandwidth percentage of 6.3% at a return loss of -10 dB. At the specific frequency of 2.45 GHz, the return loss is recorded at -22.12 dB.

2.2.1 Far-Field Radiation Pattern Analysis

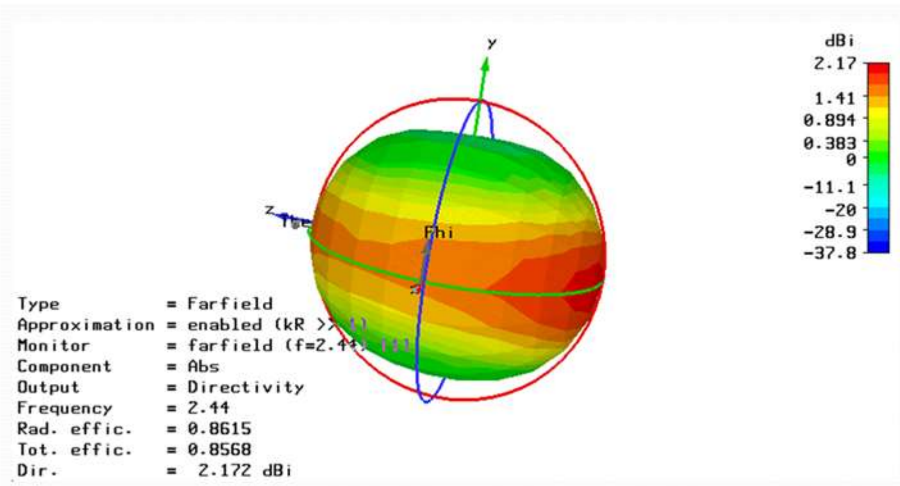

Fig 3- displays the far-field radiation pattern for the designed monopole antenna at a frequency of 2.45 GHz.

The pattern reveals an omnidirectional radiation characteristic, indicating that the antenna effectively radiates power in all directions. This feature is particularly advantageous for WLAN and Bluetooth applications, as it allows for optimal signal reception from various angles, which is essential for small devices. Furthermore, the pattern demonstrates circular polarization, with the electric and magnetic fields exhibiting similar values across most directions

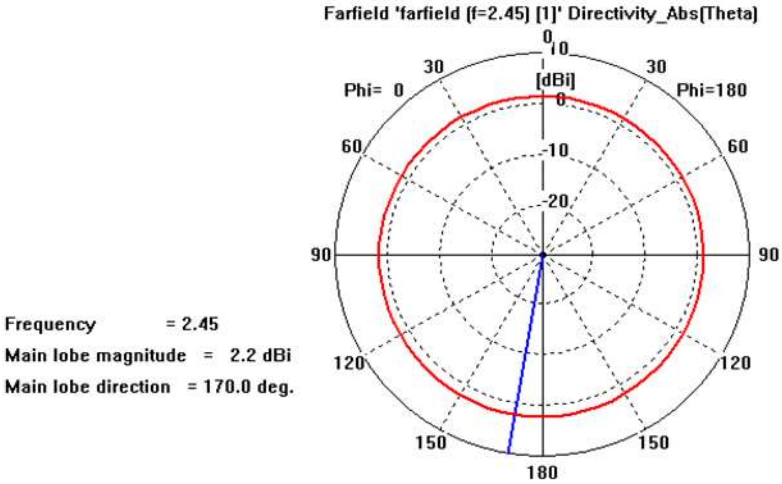

Fig 4 - E- plane radiation pattern result of proposed monopole antenna

The results derived from the analysis are summarized as follows:

Frequency: 2.45 GHz

Main lobe magnitude: 2.2 dBi

Main lobe direction: 170.0 degrees

Additionally, Figure 5 presents the H-plane radiation pattern simulation results for the monopole antenna design.

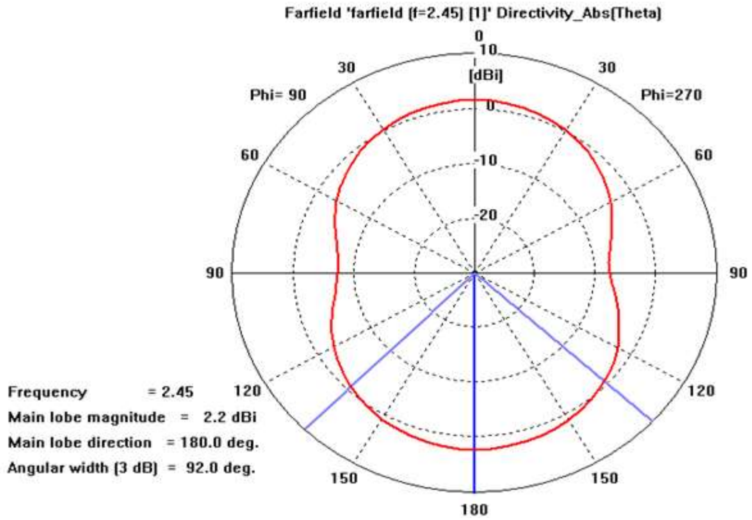

Fig 5 - presents the 2D H- plane radiation pattern result of monopole antenna

The outcomes from this analysis are outlined below:

1. Frequency: 2.45 GHz
2. Main lobe magnitude: 2.2 dBi
3. Main lobe direction: 180.0 degrees
4. Angular width (3dB): 92 degrees

The antenna shows a good radiation pattern with excellent gain.

Measurement vs simulation results

Fig 6- Fabrication of Monopole antenna

Fig 7- The ground plane of Monopole antenna

The return loss parameter was accurately measured using the Marconi Scalar Analyzer 6204. This device provided detailed data on return loss, presented both graphically and textually. Figure 8 illustrates a comparison between the simulated and measured return loss results for the monopole antenna.

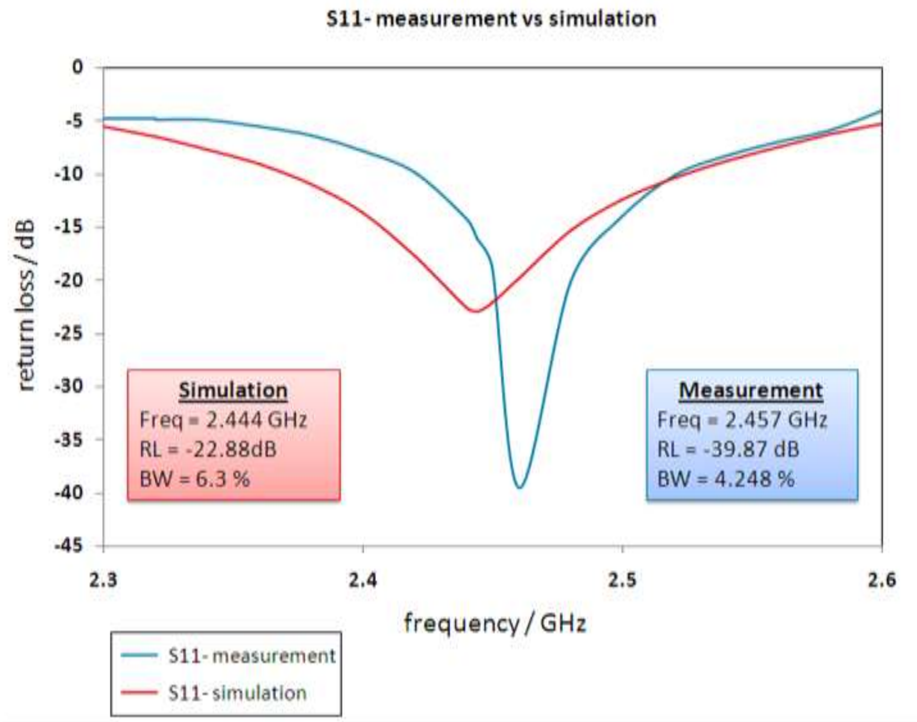

Figure fig 8- Return Loss results for simulation and fabrication of Monopole antenna structure 1

From the graph, it is clear that the resonant frequency occurs at 2.444 GHz in the simulation and 2.457 GHz in the fabrication result, with return loss values of -22.88 dB and -39.87 dB, respectively. Additionally, the antenna bandwidth is 6.3% in the simulation and 4.248% in the measured result.: The measured return loss indicates a better performance than the simulated result, particularly with a significantly lower return loss of -39.87 dB compared to -22.88 dB in the simulation. However, the bandwidth is slightly narrower in the fabricated design. This suggests that while the fabricated antenna offers improved impedance matching, there may be a trade-off in terms of bandwidth [7].

Table 1 - return loss at 2.45 is almost same for the simulation and the fabrication result.

Monopole antenna structure 1	**Simulated results**	**Measured results**
Resonant frequency f_r	*2.444 GHz*	*2.457 GHz*
Return Loss at f_r	*- 22.88 dB*	*- 39.87 dB*
Bandwidth	*6.3%*	*4.248%*

The paper shows that the similarities between the simulated and measured results of the this antenna . These indicate a good impedance matching is achieved in designing the patches and feeds.

3. Conclusion

In conclusion, this research successfully designed, simulated, fabricated, and tested Shorted Patch and Monopole antennas operating at 2.45 GHz for small devices and Bluetooth applications. Utilizing a range of tools, including CST Design Environment and the Marconi Scalar Analyzer, the antennas were shown to meet IEEE 802.11b standards for WLAN and Bluetooth applications, operating within the 2.4 GHz ISM band [8]. Measurement results demonstrated excellent impedance matching, with return losses exceeding -20 dB. While the Monopole antenna exhibited close alignment between simulated and measured results

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